Low Pressure and Low Temperature Hermetic Wafer Bonding Using Microwave Heating

Category: Fabrication Technology

Nasser K. Budraa, H. W. Jackson, M. Barmatz, William T. Pike, John D. Mai
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

Abstract

We bonded gold on silicon substrates (Au/Si) for a MEMS application by using microwave radiation in a single-mode cavity. Microwave radiation selectively heats materials, the energy is deposited in the metallic portion of the substrates in this application. This concentration of the energy forms the bonding rather quickly and with minimal heating of the substrate. The bonding process time allows for minimal diffusion of the Si into the metallization. Since no pressure is applied to form the bonding mechanical stresses are minimized. The substrates bonded by our technique formed a hermetically sealed micron sized cavity. Preliminary He fine leak tests from these bonded samples show leak rates on the order of 3×10^{9} atom cc/s. Since the process is performed in a vessel evacuated to 25×10^{-6} Torr, this means the pressure in the bonded cavity should not return to standard atmospheric value for approximately 1.2 years.

hermetic sealing
MEMS bonding
microwave bonding

Introduction

Micro Electro-Mechanical Systems (MEMS) are touted to be the next technological revolution since the invention of the microprocessor. Their use is expected to be wide spread in various fields ranging from the scientific to the commercial. The rapid progress made in this field has been helped by the existence of the infrastructure of the silicon industry. However, numerous problems exist that have impeded this progress, among these are the bonding of various MEMS components and hermetically sealing a cavity made up of these components. Bonding of MEMS has so far been limited to anodic bonding, thermo-compression or a polymer adhesive each with some advantages and limitations. We are introducing a novel material that has a low imaginary dielectric constant ε″, however energy is deposited in a skin depth (~ 1 μm) of a metal due to its high ε″. This feature results in selective heating within the substrate. No pressure is required in microwave bonding, hence mechanically induced stresses are minimized. Heating of the silicon wafers is limited by the wafers ε″(generally small for pure silicon), and the heat deposited into the metal and later conducted to the substrate.

Experiment

Sample Preparation

Simple test pieces were fabricated using the following process. Starting with a 4 in. Si wafer, a single mask was used to lithographically define the concentric square bond area. Then 150 Å of Cr and 1200 Å of Au were deposited and the underlying photoresist was lifted off. The wafer was then etched in an EDP (ethylenediamene+pyrocathecol) solution for approximately 80 minutes. Figure 1 shows some test pieces with the 3 mm x 3 mm x 100 μm deep etch pit surrounded by a 2 mm wide plateau of Au on all sides. The wafer was diced and microwave bonding experiments were performed. Each bonded device is made up of two 5 mm x 5 mm x 500 μm test pieces.

Microwave Sample-Bonding

The microwave bonding was performed in a 12.7 cm diameter cylindrical cavity excited by an azimuthally symmetric TM_{010} mode at 2.45 GHz. The loaded Q of the empty cavity was approximately 2500. The Au coated parts of the substrates were simply placed on top of each other in order to fuse the metallic surfaces together. The experiment was performed in a high vacuum (~25 μTorr) to avoid the creation of plasma. The wafers were simply placed on top of each other without applying pressure inside of a microwave transparent (quartz) test tube. The wafers were placed at the highest magnetic field intensity in the cavity and were carefully oriented parallel to the magnetic field. Various power-time profiles were applied to achieve the bonding, some of these were as high-power and short-time as 300 Watt pulse for 2-3 second duration. Other profiles lasted for 30 seconds at 100 Watts. At this point there is not enough data to indicate the optimum profile to achieve the bonding. A completely different rout to achieve the bonding would be to use a different wafer orientaion and apply the electric field maxima to couple to the samples metallization.

Hermetic Sealing Tests

The bonded test samples were placed in a pressure bomb chamber that was initially evacuated for 1 hour to test for gross leaks. The chamber was slowly back filled with FC-40 fluid to atmospheric pressure and pressurized overnight to 60 psi with FC-72 fluid. The samples were then removed from the bomb and quickly submerged into hot FC-40 at 125°C. Three samples were tested and absolutely no bubbles appeared which indicates no gross leaks.
For a quantitative hermeticity test of this bonding method, three test samples were also placed in a helium pressure bomb that was pressurized to 60 psi for two hours. Afterwards, the samples were removed and leak tested in a Varian Model 947 mass spectrometer. This showed leak rates for the test pieces ranging from 2.8×10^{-9} atm. cc/s to 3.6×10^{-9} atm. cc/s that were comparable to the background limit of this instrument (2×10^{-9} atm cc/s). The samples were broken in two parts and the results of a scanning electron microscopy tests are shown in Figure 2 and 3. In Figure 3 the 20,000x magnification shows the fusion of the two metallic layers into one.

Conclusions

We have bonded MEMS sized Au/Si substrates to form a hermetically sealed enclosure in a single mode microwave cavity. The concentration of the heat to the surface of the metal joins the two surfaces on the two substrates without applying any pressure. The substrates temperature rise is due mostly to the heat deposited in the metal and conducted to these substrates. Diffusion of the silicon from the substrate to the metallization is probably very limited by the length of time used to form the bonding with this method.

Future tests are planned that will include bonding different combinations of substrates and metallic layers (e.g. platinum, titanium). Bonding wafers that include electronic devices and scaling up of the bonding to process complete wafers is also under study.

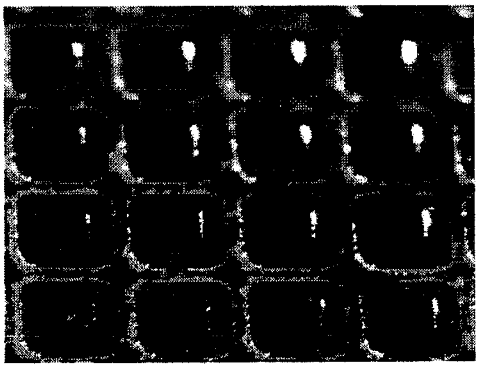

Figure 1. Unbonded test pieces.

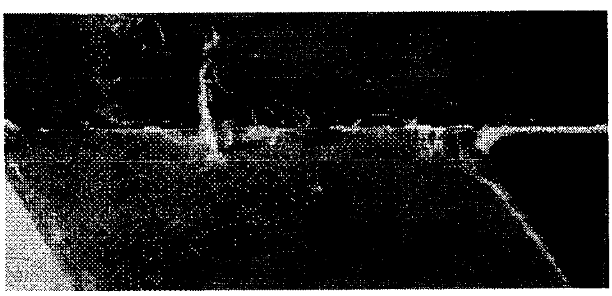

Figure 2. SEM micrograph of Au/Au bond at 500x magnification

Figure 3. Close up of Au/Au. (20,000x magnification)